



US009478389B2

(12) **United States Patent**  
**Nomaguchi et al.**

(10) **Patent No.:** **US 9,478,389 B2**  
(45) **Date of Patent:** **Oct. 25, 2016**

(54) **SCANNING ELECTRON MICROSCOPE**

(71) Applicant: **Hitachi High-Technologies Corporation**, Minato-ku, Tokyo (JP)

(72) Inventors: **Tsunenori Nomaguchi**, Tokyo (JP);  
**Toshihide Agemura**, Tokyo (JP)

(73) Assignee: **Hitachi High-Technologies Corporation**, Tokyo (JP)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/422,374**

(22) PCT Filed: **Jul. 1, 2013**

(86) PCT No.: **PCT/JP2013/067965**

§ 371 (c)(1),

(2) Date: **Feb. 19, 2015**

(87) PCT Pub. No.: **WO2014/030433**

PCT Pub. Date: **Feb. 27, 2014**

(65) **Prior Publication Data**

US 2015/0221468 A1 Aug. 6, 2015

(30) **Foreign Application Priority Data**

Aug. 22, 2012 (JP) ..... 2012-182833

(51) **Int. Cl.**

**H01J 37/10** (2006.01)

**H01J 37/28** (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ..... **H01J 37/10** (2013.01); **H01J 37/1413**  
(2013.01); **H01J 37/1471** (2013.01); **H01J**  
**37/16** (2013.01);

(Continued)

(58) **Field of Classification Search**

USPC ..... 250/491.1

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,219,732 A \* 8/1980 Nakagawa ..... H01J 37/141  
250/311  
4,831,267 A \* 5/1989 Brunner ..... G01T 1/28  
250/305

(Continued)

FOREIGN PATENT DOCUMENTS

JP 57-118356 A 7/1982  
JP 2004-14229 A 1/2004

(Continued)

OTHER PUBLICATIONS

International Search Report (PCT/ISA/210) dated Aug. 13, 2013,  
with English translation (Ten (10) pages).

*Primary Examiner* — Phillip A Johnston

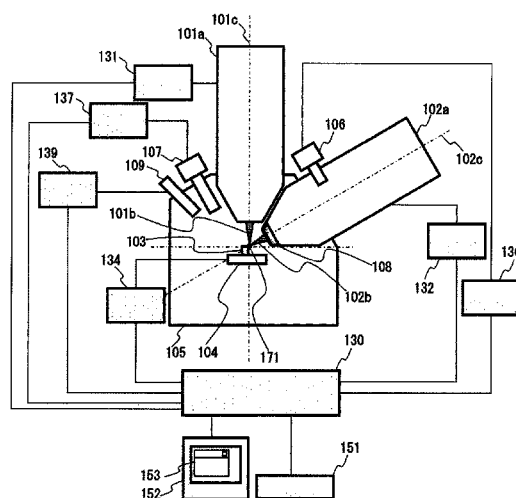
(74) *Attorney, Agent, or Firm* — Crowell & Moring LLP

(57)

**ABSTRACT**

The present invention provides a composite charged particle beam device which is provided with two or more charged particle beam columns and enables high-resolution observation while a sample is placed at the position of a cross point. The present invention has the following configuration. A composite charged particle beam device is provided with a plurality of charged particle beam columns (**101a**, **102a**), and is characterized in that a sample (**103**) is disposed at the position of an intersection point (**171**) where the optical axes of the plurality of columns intersect, a component (**408a**, **408b**) that forms the tip of an objective lens of the charged particle beam column (**102a**) is detachable, and by replacing the component (**408a**, **408b**), the distance between the intersection point (**171**) and the tip of the charge particle beam column can be changed.

**7 Claims, 10 Drawing Sheets**



(51) **Int. Cl.**

*H01J 37/147* (2006.01)  
*H01J 37/22* (2006.01)  
*H01J 37/305* (2006.01)  
*H01J 37/317* (2006.01)  
*H01J 37/26* (2006.01)  
*H01J 37/141* (2006.01)  
*H01J 37/16* (2006.01)  
*H01J 37/30* (2006.01)

(52) **U.S. Cl.**

CPC ..... *H01J 37/222* (2013.01); *H01J 37/261*  
 (2013.01); *H01J 37/265* (2013.01); *H01J*  
*37/28* (2013.01); *H01J 37/305* (2013.01);  
*H01J 37/3005* (2013.01); *H01J 37/3056*  
 (2013.01); *H01J 37/3178* (2013.01); *H01J*  
*2237/0245* (2013.01); *H01J 2237/032*  
 (2013.01); *H01J 2237/12* (2013.01); *H01J*  
*2237/31745* (2013.01)

## (56)

**References Cited**

## U.S. PATENT DOCUMENTS

7,221,731 B2 \* 5/2007 Yada ..... G21K 7/00  
 250/396 ML  
 8,247,782 B2 \* 8/2012 Edinger ..... C23F 4/00  
 250/306  
 2005/0285037 A1 12/2005 Nakamura et al.  
 2006/0076489 A1 4/2006 Ohshima et al.

## FOREIGN PATENT DOCUMENTS

JP 2006-12583 A 1/2006  
 JP 2006-114225 A 4/2006  
 JP 2008-123891 A 5/2008  
 JP 2010-157370 A 7/2010  
 JP 2011-222525 A 11/2011  
 JP 2011-258451 A 12/2011

\* cited by examiner

FIG. 1

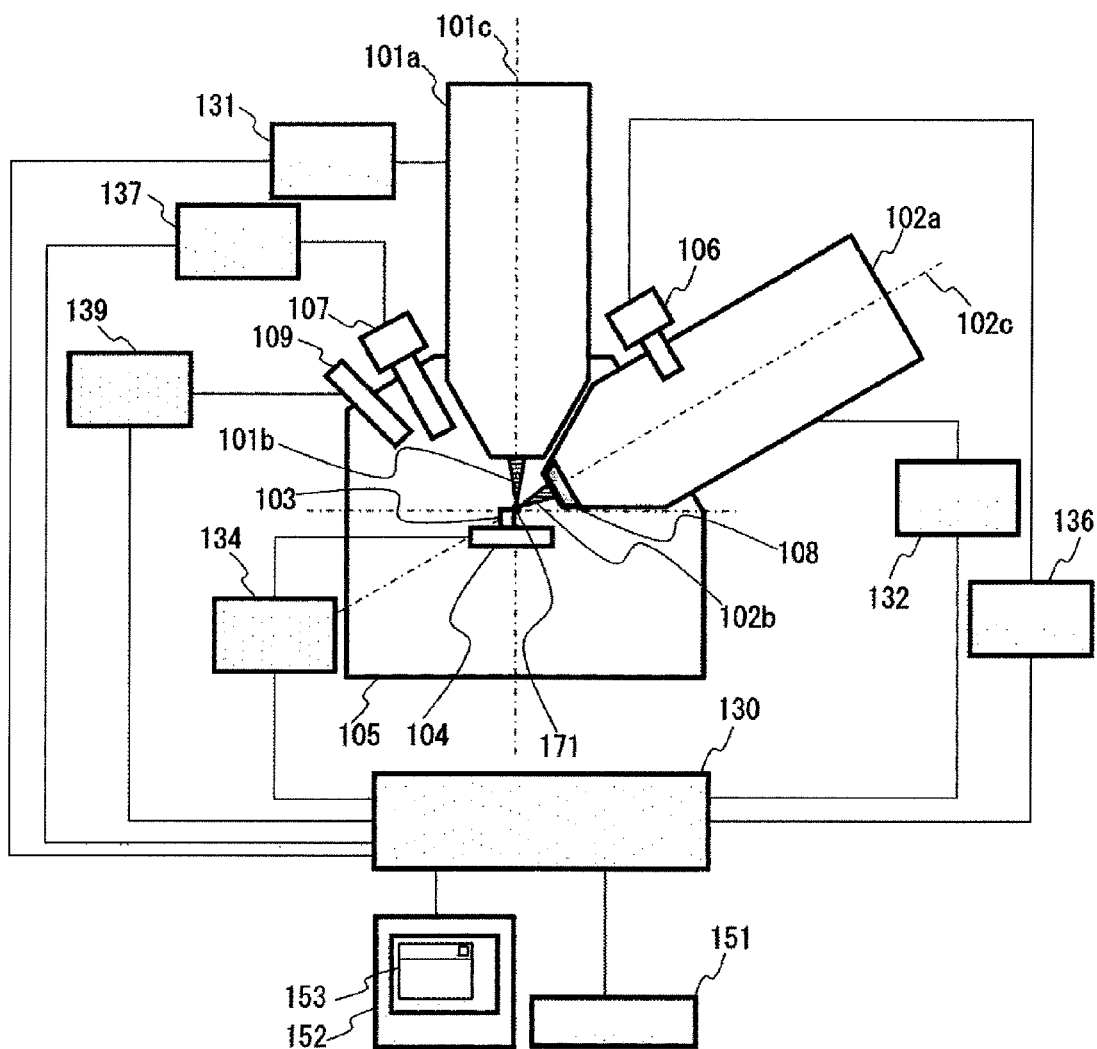


FIG. 2

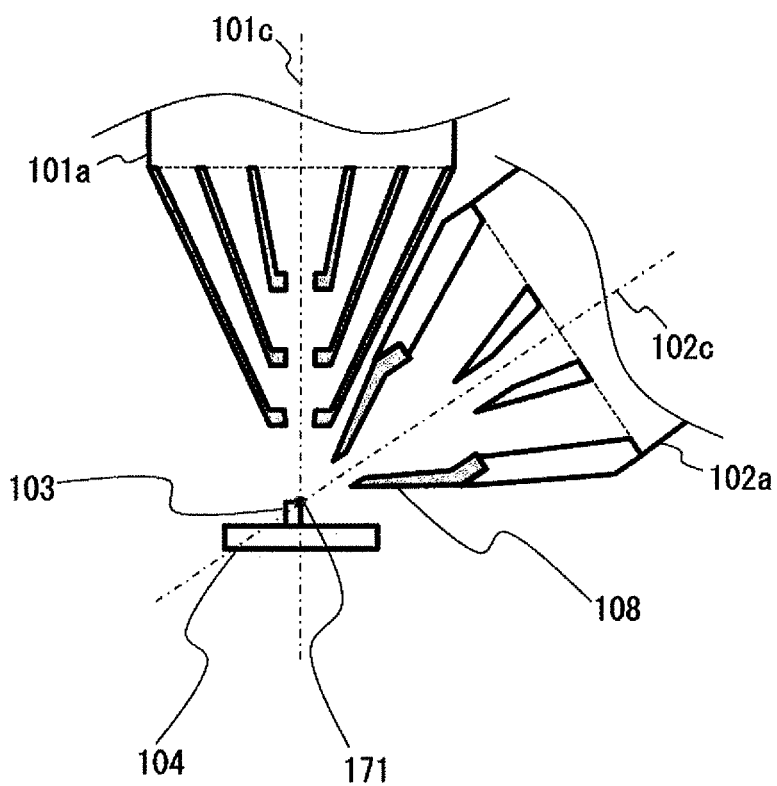


FIG. 3

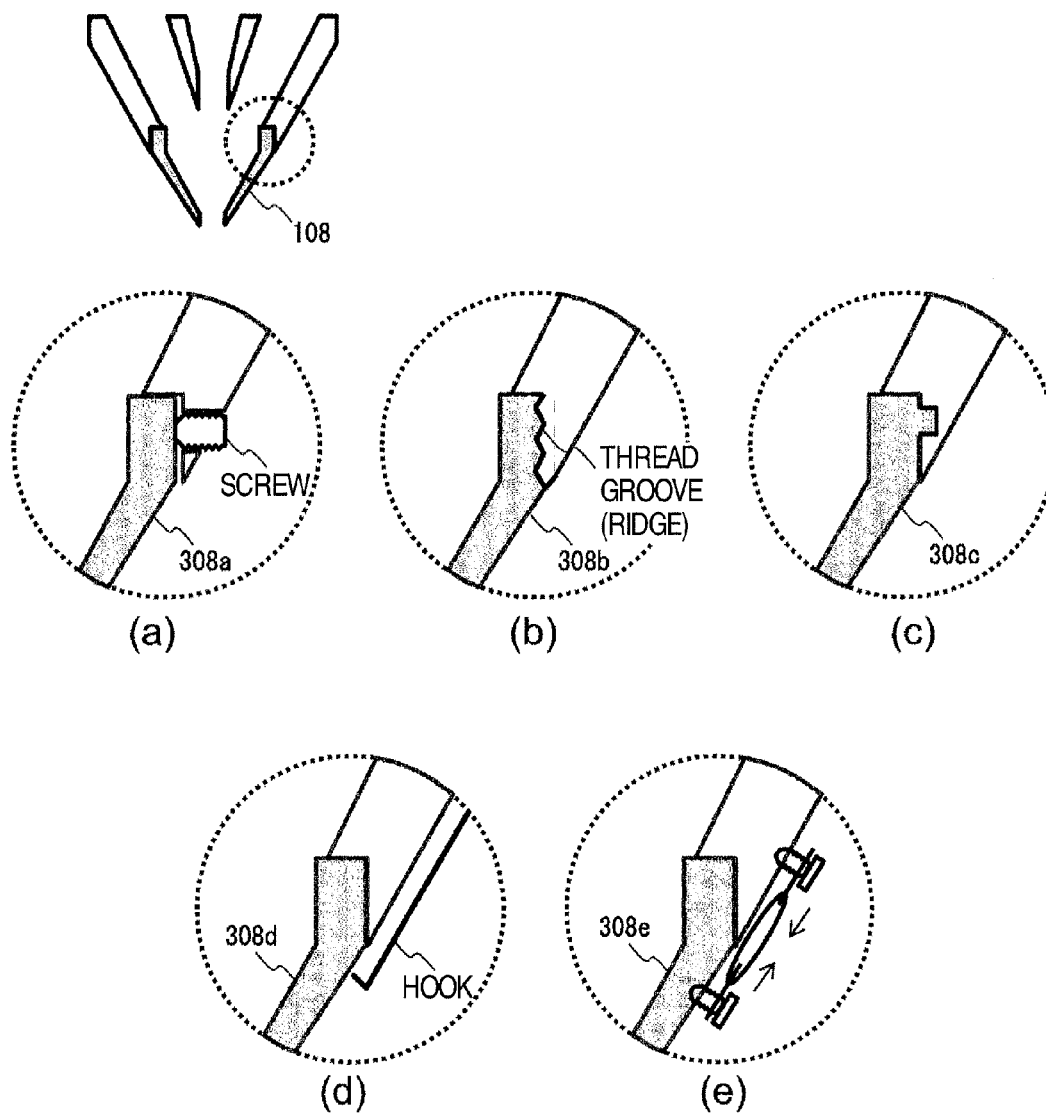


FIG. 4

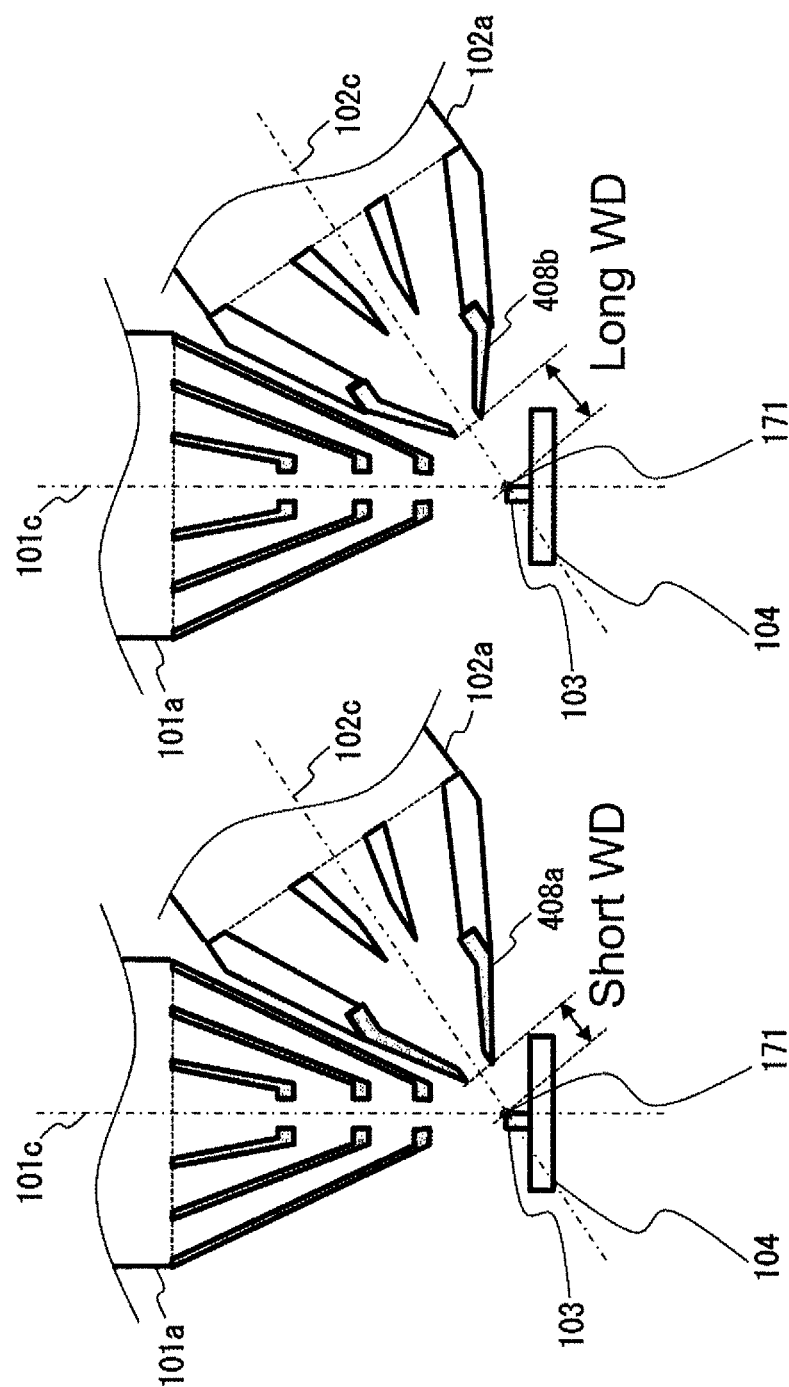


FIG. 5

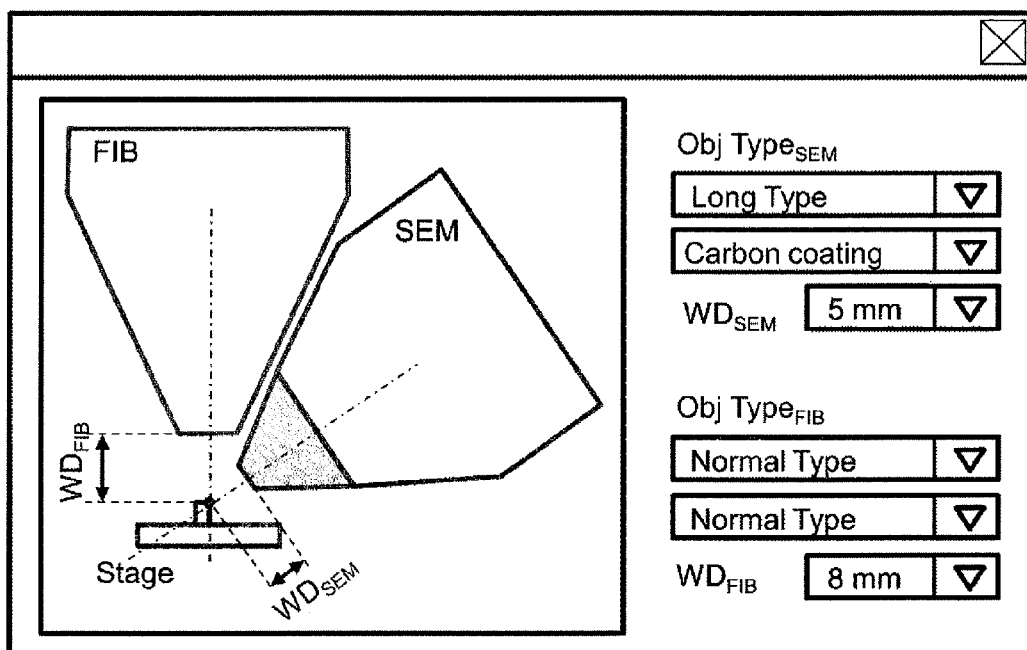


FIG. 6

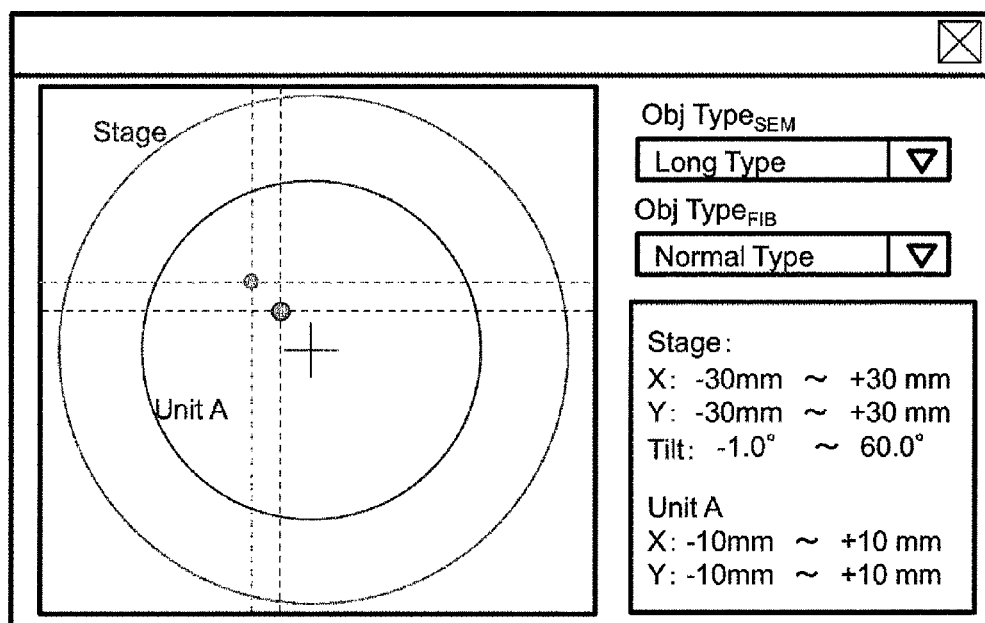




FIG. 7

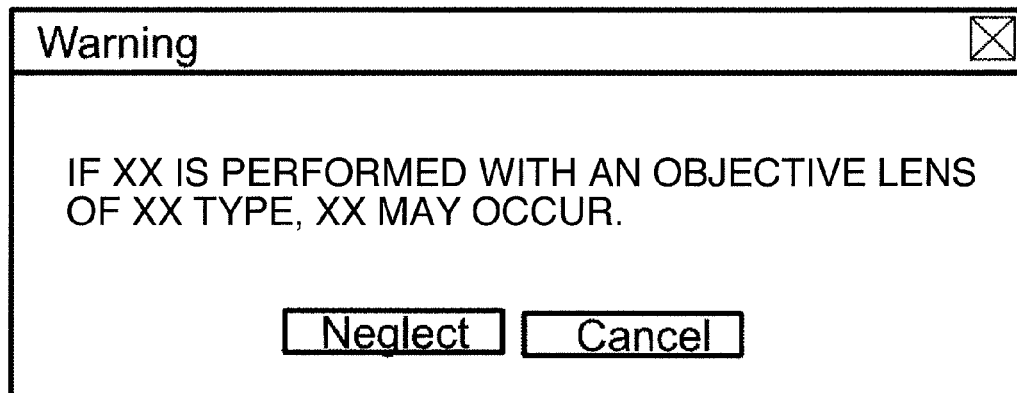
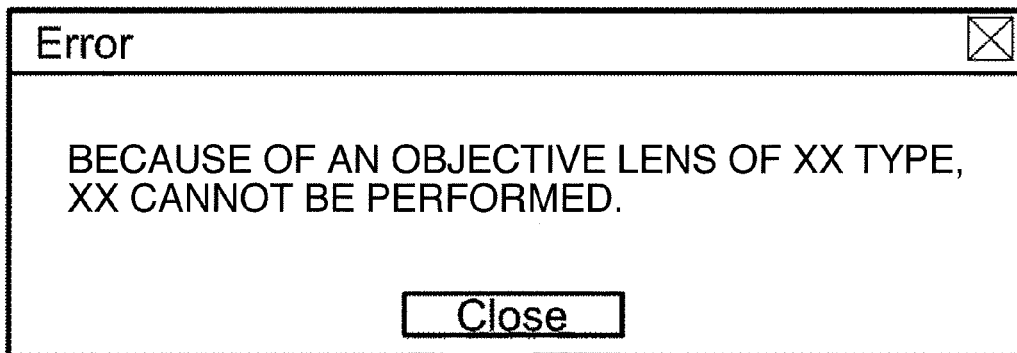


FIG. 8

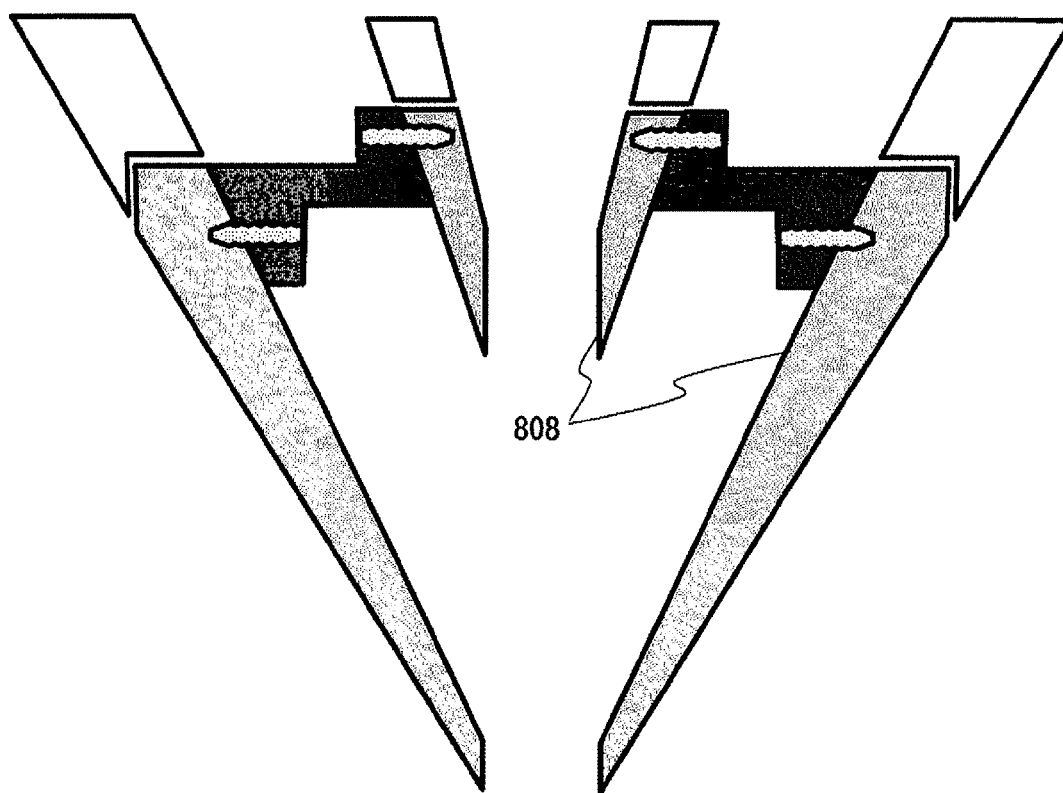


FIG. 9

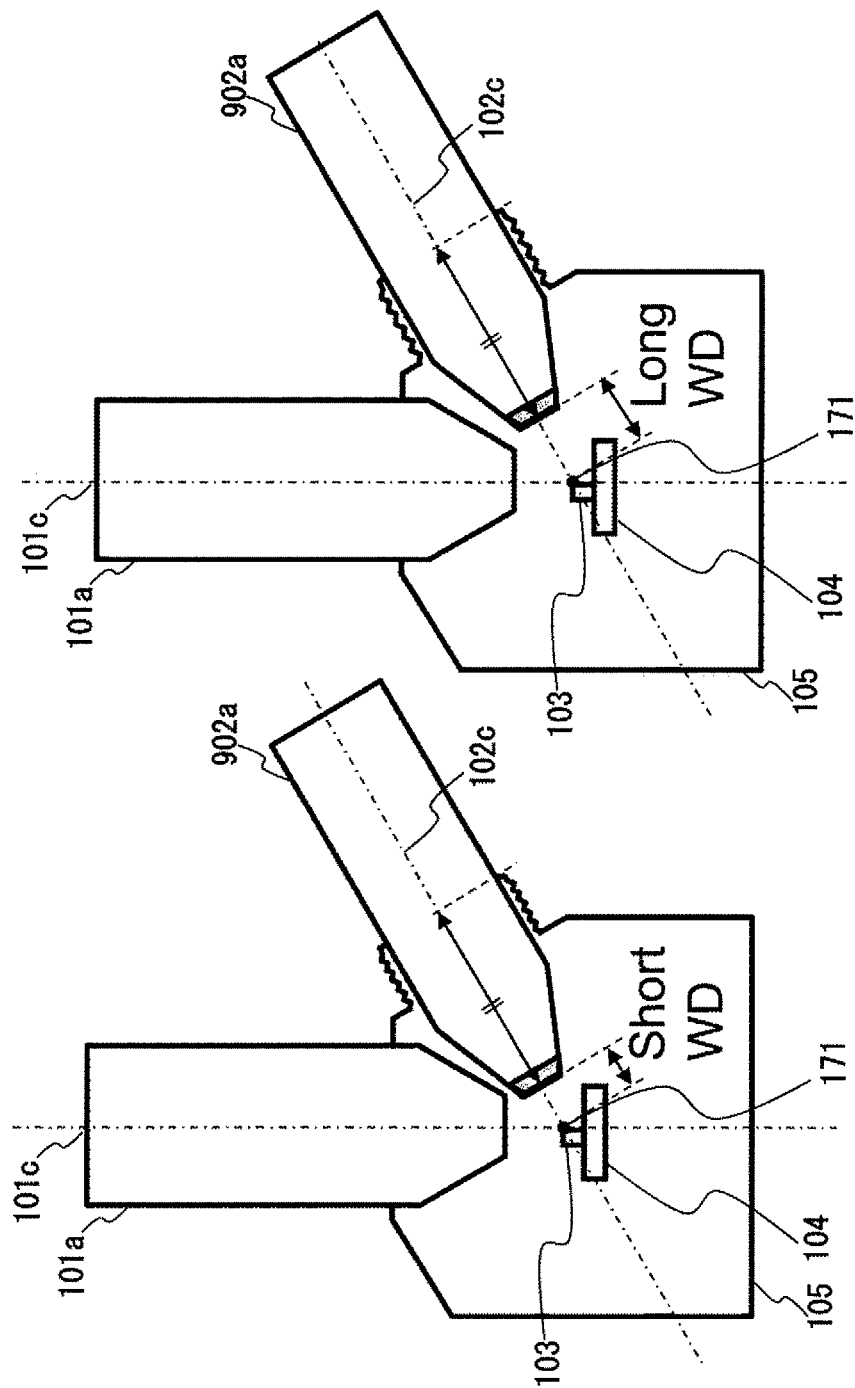
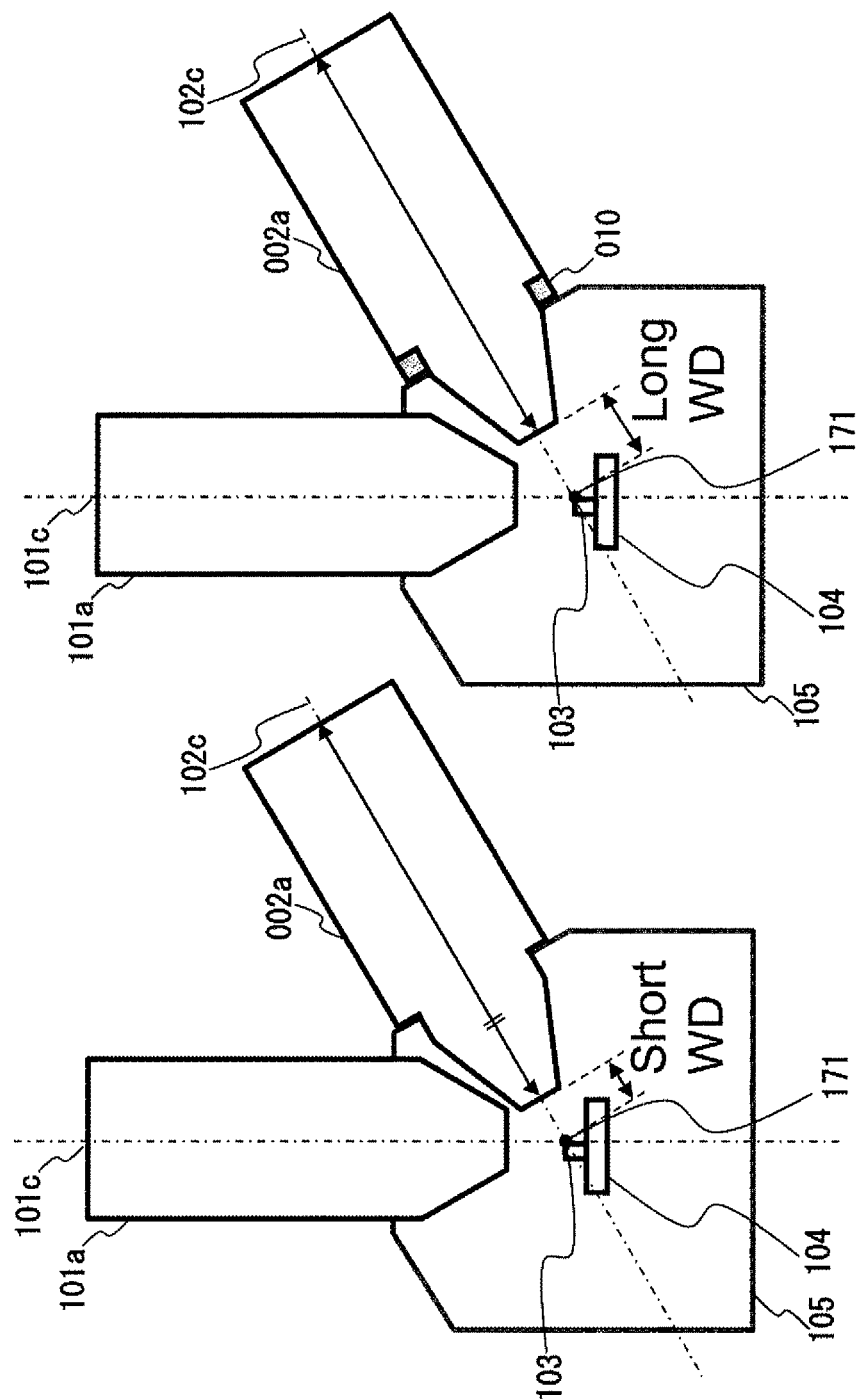


FIG. 10



## SCANNING ELECTRON MICROSCOPE

## TECHNICAL FIELD

The present invention relates to a scanning electron microscope.

## BACKGROUND ART

A composite charged particle beam device, which is provided with both a scanning electron microscope (SEM) and a focused ion beam (FIB), has a feature that a region which is processed (or being processed) using a focused ion beam can be observed in situ with a SEM at high resolution. Therefore, it is an essential tool in manufacturing samples for transmission electron microscope observation and also in various industrial fields, such as the field of semiconductor, the field of material sciences, and the field of medicine where nanometer-order micro-processing is required.

Cited literature 1 discloses an objective lens for an electron microscope system having a minimum magnetic field outside the objective lens.

## CITATION LIST

## Patent Literature

Patent Literature 1: JP-A-2011-222525

## SUMMARY OF INVENTION

## Technical Problem

The inventors have made intensive studies on a composite charged particle beam device and acquired the following knowledge.

A device provided with only one charged particle beam column such as, for example, a SEM may have a sample positioned on the optical axis of the SEM. Therefore, the distance between the sample and the charged particle beam column can be changed appropriately according to application. For example, when high-resolution observation is desired, observation is performed with a sample positioned closer to a charged particle beam column.

On the other hand, in the case of a device provided with two or more charged particle beam columns such as, for example, a device provided with a SEM and a FIB, a position where SEM observation and FIB processing can be performed without moving a sample is limited to only a single point (a cross point) where the optical axis of the SEM and the optical axis of the FIB intersect. Therefore, it is typical to use a FIB-SEM device at a cross point, and the distance between the sample and the end of each charged particle beam column is fixed.

The device provided with two or more charged particle beam columns can also have a sample disposed at a position other than the cross point, but in such a case only one of the charged particle beam columns is used. For example, where a FIB-SEM device has a sample approached to a SEM column, usage is limited to the SEM only. To perform processing with the FIB, it is necessary to move the sample to the cross point again.

Also, a material of a component which exists near the sample has great influences on the composition analysis of the sample. For example, if the same substance as an element to be detected is used for the component of the tip of the objective lens when X-ray analysis is performed, it

cannot be distinguished whether it is a signal from the sample or a signal from the tip of the objective lens. As countermeasures, there is a method such as applying plating of a material not containing the element to be analyzed to the tip of the objective lens. But, when samples to be analyzed widely vary, it becomes difficult to cope with by plating.

## Solution to Problem

The present invention pertains to a scanning electron microscope, including: an electron beam column, which includes a tip of an objective lens of the electron beam column configured with a detachable component so that a tip of an objective lens made of a different material can be attached thereto.

Other embodiments are described in the column of DESCRIPTION OF EMBODIMENTS.

## Advantageous Effects of Invention

According to the present invention, system peak can be handled by preparing plural tips of different materials of objective lens.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows a schematic diagram of a first embodiment; FIG. 2 shows a magnified view of the vicinity of a cross point;

FIG. 3 shows examples of fixing a component of the tip of an objective lens;

FIG. 4 shows an example that different components are attached to the tip of the objective lens;

FIG. 5 shows an example of a GUI screen clearly indicating a type of a component of the tip of the objective lens;

FIG. 6 shows an example of a GUI screen clearly indicating a movable range of each unit;

FIG. 7 shows an example of a warning or error screen;

FIG. 8 shows an example where the component of the tip of the objective lens is an assembly;

FIG. 9 shows a schematic diagram of a second embodiment; and

FIG. 10 shows a schematic diagram of a third embodiment.

## DESCRIPTION OF EMBODIMENTS

Novel features and effects of the present invention are described by considering the drawings. In the individual drawings, the same reference numerals are given to common constituents.

## Embodiment 1

[Construction of Composite Charged Particle Beam Device]

First, a device construction in the present embodiment is described. FIG. 1 shows a schematic diagram of a composite charged particle beam device of the present embodiment. FIG. 2 shows a magnified view of the vicinity of a cross point.

In FIG. 1, the composite charged particle beam device is provided with an ion beam column **101a**, an ion beam column controller **131** for controlling the ion beam column **101a**, an electron beam column **102a**, an electron beam column controller **132** for controlling the electron beam column **102a**, a sample stage **104** on which a sample **103** can be mounted, a sample stage controller **134**, a sample chamber **105**, detectors **106**, **107** for detecting electrons generated

when the sample **103** is irradiated by an electron beam **102b** or an ion beam **101b**, detector controllers **136**, **137** which control the respective detectors, an X-ray detector **109**, an X-ray detector controller **139** which controls the X-ray detector, an integrated computer **130** which controls operations of the entire composite charged particle beam device, a controller (such as a keyboard or a mouse) **151** with which an operator inputs various instructions such as irradiation conditions and a position of the sample stage, and one or a plurality of displays **152** which display a GUI screen **153** for controlling the device, a status of the device, acquired information (including an image), and the like. The status of the device, the acquired information, and the like may be included in the GUI screen **153**.

The ion beam column **101a** is a system including all necessary constituents for a FIB such as an ion source for generating the ion beam, a lens for focusing the ion beam, and a deflection system for scanning and shifting the ion beam. Similarly, the electron beam column **102a** is a system including all necessary constituents for a SEM such as an electron source for generating the electron beam, a lens for focusing the electron beam, and a deflection system for scanning and shifting the electron beam. Moreover, a tip of an objective lens of the electron beam column **102a** is configured with a detachable component **108**.

And, the ion beam column **101a** and the electron beam column **102a** are mounted on the sample chamber **105**, and the ion beam **101b** travelling through the ion beam column **101a** and the electron beam **102b** travelling through the electron beam column **102a** are primarily focused on an intersection (a cross point **171**) of an optical axis **101c** of the ion beam column and an optical axis **102c** of the electron beam column. Besides, as for the ion beam **101b**, gallium ions are generally used, but ion species do not matter for the purpose of processing the sample. Furthermore, the ion beam is not limited to a focused ion beam and may be a broad ion beam.

Incidentally, in the present embodiment, the ion beam column **101a** is vertically arranged and the electron beam column **102a** is obliquely arranged; however, they are not restrictive and the ion beam column **101a** may be obliquely arranged and the electron beam column **102a** may be vertically arranged. Both the ion beam column **101a** and the electron beam column **102a** may also be obliquely arranged. Moreover, there may be adopted a triple-column configuration having a Ga focused ion beam column, an Ar focused ion beam column, and an electron beam column.

The sample stage **104** can make planar movement and rotational movement. Furthermore, a position necessary for processing with the ion beam or observation can also be moved to an ion beam irradiation position or to an observation position with the electron beam.

The component **108** which forms the tip of the objective lens desirably has an overall length of **35** mm or less considering the electron beam column **102a**, the ion beam column **101a**, and the sample stage **104**.

The detectors **106**, **107** are respectively mounted on the electron beam column **102a** and the sample chamber **105**. Moreover, each of the detector controllers **136**, **137** has a circuit or an arithmetic processing unit to perform arithmetic processing of a detection signal and to form an image. It is noted that, for the detectors **106**, **107**, composite charged particle detectors capable of detecting ions in addition to electrons may be used. Also, in addition to the detector **107**, the sample chamber **105** may be equipped with detectors such as a tertiary electron detector, a STEM detector, a backscattered electron detector, and a low energy loss elec-

tron detector as second, third, fourth, and fifth detectors. Furthermore, a mass spectrometer or the like may be mounted in addition to the X-ray detector **109**.

In addition to the above, the sample chamber **105** is also equipped with a gas deposition unit, a micro sampling unit, and the like. The individual drive mechanisms such as the deposition unit and the micro sampling unit are also provided with controllers respectively. The gas deposition unit used for manufacturing of a protective film and/or for marking stores a deposition gas which forms a deposit film by irradiation of a charged particle beam and can supply it from a tip of a nozzle when necessary. The micro sampling unit that picks up a specific portion of a sample while being used together with processing and cutting of the sample with the FIB includes a probe which can be moved by a probe driving unit within the sample chamber **105**. The probe is used to remove a minute sample piece which is formed in the sample and/or to supply an electric potential to the sample by contacting to the sample surface. In addition, the sample chamber **105** may also be equipped with a cold trap, an optical microscope, and the like. Incidentally, as for the sample **103**, steel, light metals, and polymer-based macromolecule substances may also be conceived other than a semiconductor sample. Besides, the integrated computer **130** and the respective controllers can communicate with each other.

[Fixing Method of Tip of Objective Lens]

Fixing methods of the component **108** of the tip of the objective lens are variously considered, such as a fixing method with a screw, a method that the component itself is threaded, and a fixing method by compression bonding. Their examples are described below.

FIG. **3(a)** shows a fixing example with a screw. Fixing can be made using one screw, but using two or more screws is desirable in view of stability. In addition, fixing using three to four screws is desirable when adjustment of the component position during assembly is considered. It is because use of three to four screws provides an advantage that the position of a component **308a** can be adjusted according to tightening degrees of the mutual screws.

FIG. **3(b)** shows an example that a component **308b** itself is threaded. It is advantageous that the number of components does not increase by fixing.

FIG. **3(c)** shows an example of fixing by matching a groove and a projection. In FIG. **3(c)**, a component **308c** has a projection, and the objective lens body has a groove, but the vice versa is also possible. Thus, they can be attached and detached more easily.

In addition to the above, there may be conceived various methods such as a method of fixing by catching a component **308d** (FIG. **3(d)**), a method of pulling up a component **308e** (FIG. **3(e)**), and a fixing method using a detachable adhesive material. Also, a plurality of methods may be combined in order to fix the component **108**.

Effects of constructing the tip of the objective lens of the electron beam column **102a** with the detachable component **108** are described.

By constructing the tip of the objective lens with a detachable component, the tip of the objective lens having a different structure can be attached according to usage. As a result, there can be attained effects, for example, (1) being capable of changing the distance (Working Distance: WD) between the sample and the lower surface of the objective lens, (2) facilitating repair when the tip of the objective lens is damaged or contaminated, and (3) being capable of coping with a system peak by preparing a plurality of tips of the

objective lens of different materials. The individual effects are described below in detail.

[(1) Effects Regarding Capability of Changing WD]

Generally, resolution of the SEM is improved when the WD is shortened. On the other hand, when the WD is shortened, detection efficiency of the detector **107** and/or the X-ray detector **109** which are mounted on the sample chamber lowers. Therefore, it is desired that the WD is changed according to usage. A general-purpose SEM device which is equipped with a single charged particle beam column can comply with it by moving the sample stage, and it is carried out on a daily basis. But, for a FIB-SEM device, which is equipped with two or more charged particle beam columns, the sample stage **104** is adjusted to position the sample **103** at the cross point **171**. Therefore, the position of the sample stage **104** in the optical axis direction is basically fixed. Namely, the WD is basically determined according to mounting positions of the ion beam column and the electron beam column. However, the WD can be changed by constructing the tip of the objective lens of the electron beam column **102a** with the detachable component **108**. That is, the WD is changed by changing the lower surface of the objective lens without moving the position of the sample stage **104**. For example, as shown in FIG. 4, when high-resolution observation becomes significant, a component **408a** for the tip of the objective lens is made long and, when a priority is desired to be given to the driving range of the sample stage or the detection efficiency of the detector **107** and/or the X-ray detector **109** than to the resolution, a component **408b** for the tip of the objective lens may be made short.

Furthermore, when the component **408b** for the tip of the objective lens is made short, the driving ranges of the deposition unit and the micro sampling unit can also be increased. In addition, the cold trap and the like can also be made closer to the sample. Namely, the versatility of the composite charged particle beam device can be improved.

In addition, it is convenient if the display of the GUI screen **153** is changed for each position of the tip of the objective lens. It is convenient if there are functions, for example, to clearly indicate types of attached objective lenses (FIG. 5), to clearly indicate the distance between the cross point and the end of each charged particle beam column (FIG. 5), and/or to clearly indicate the driving range of each unit for every type of objective lenses (FIG. 5). Incidentally, the methods of indication may be displays with letters and/or numerical values or diagrams such as figures and/or colors. Both of them may also be displayed.

[(2) Regarding Easiness of Repair in Case of Damage or Contamination of Tip of Objective Lens]

A gas discharged from the sample, sputtered particles due to ion beam, and the like adhere to a component near the sample. The performance of the charged particle beam device is occasionally deteriorated by the adhered substance. For example, there might be occurrence of bending of a primary beam or bending of electrons discharged from the sample due to an insulating material adhered to the tip of the objective lens. In such a case, works such as cleaning of the objective lens and, additionally, an exchange of a set of objective lenses become necessary. Moreover, the cleaning works have risk that the objective lens may be damaged during the works.

However, by constructing the tip of the objective lens of the electron beam column **102a** with the detachable component **108**, a measure of replacement can be taken against contamination and/or damage of the tip of the objective lens.

Thus, much easier repair against contamination and/or damage of the tip of the objective lens with lower risk than before becomes possible.

[(3) Regarding Effects of being Capable of Corresponding to System Peak by Preparing Plural Tips of Different Materials of Objective Lens]

A material of a component which exists near the sample has great influences on the composition analysis of the sample. For example, if the same substance as an element to be detected is used for the component **108** of the tip of the objective lens when X-ray analysis is performed, it cannot be distinguished whether it is a signal from the sample or a signal from the tip of the objective lens. As countermeasures, there is a method such as applying plating of a material not containing the element to be analyzed to the tip of the objective lens. But, when samples to be analyzed widely vary, it becomes difficult to cope with by plating.

However, the components of the tip of the objective lens which are plated with different types of plating can be prepared by constructing the tip of the objective lens of the electron beam column **102a** with the detachable component **108**. Namely, it becomes possible to exchange the component of the tip of the objective lens according to an analysis object. Thus, a range of element analysis can be drastically improved.

Besides, it is convenient if the display of the GUI screen **153** is changed for every attached component of the tip of the objective lens (FIG. 5). Incidentally, the methods of indication may be displays with letters and/or numerical values or by a diagram. Both of them may also be shown. In FIG. 5, for example, "Obj Type<sub>SEM</sub>" means information about the electron beam column **102a**, "Long Type" means a long component, and "Carbon coating" means a component which is coated with carbon. "WD<sub>SEM</sub>" shows a working distance from the sample to the tip of the column. Information about the ion beam column **101a** at "Obj Type<sub>FIB</sub>" is also the same.

FIG. 6 shows an example of the GUI screen clearly indicating a movable range of each unit. In this GUI, the movable range of the stage and the movable range of Unit A (for example, a deposition unit, a micro sampling probe, or the like) are shown with numerical values.

Incidentally, although the objective lens on the SEM side is described in this embodiment, it is also the same on the FIB side. Furthermore, the component which forms the tip of the objective lens may be a unit which is constructed from a plurality of parts (FIG. 8) or may be divided into a plurality of parts (or units).

In addition, although a composite charged particle beam device provided with an ion beam column and an electron beam column is described in this embodiment, combinations of charged particle beam columns do not matter. For example, it may be applied to a device provided with two or more electron beam columns or a device provided with two or more ion beam columns. It may also be applied to a combination of a charged particle beam column and an optical device such as a laser.

Embodiment 2

FIG. 9 shows a structure of a composite charged particle beam device of a second embodiment. The structure of the composite charged particle beam device of the second embodiment is different from the device structure of the first embodiment in that a driving mechanism which drives an entire electron beam column is provided instead of the tip of the objective lens of an electron beam column **902a** being detachable. The rest is almost the same as the device structure of the first embodiment. This driving mechanism

can drive the entire electron beam column while the vacuum of the sample chamber is maintained.

According to the present embodiment, similar effects to “Effects regarding capability of changing WD” described for the first embodiment can be obtained. In addition, the present embodiment has an advantage that the WD can be changed while performing the

SEM observation or during the FIB processing. Furthermore, it is also convenient in this embodiment if the display of the GUI screen is changed for each position of the tip of the objective lens, similar to the first embodiment.

Incidentally, even though a mechanism which drives the entire electron beam column is adopted in the present embodiment, only the objective lens may be driven in order to change the position of the tip of the objective lens; a part of the objective lens or a part of the column which includes the objective lens may be driven, either.

Moreover, a combination of the charged particle beam columns does not matter even in this embodiment, similar to the first embodiment.

Embodiment 3

FIG. 10 shows a structure of a composite charged particle beam device of a third embodiment. The structure of the composite charged particle beam device of the third embodiment is different from the device structure of the first embodiment in that it has a mechanism in which a flange 010 of a different size is provided between the objective lens and the sample chamber instead of the tip of the objective lens of an electron beam column 002a being detachable. The rest is almost the same as the device structure of the first embodiment. According to the present embodiment, similar effects to “Effects regarding capability of changing WD” described for the first embodiment can be obtained. Moreover, it is also convenient in this embodiment if the display of the GUI screen is changed for each position of the tip of the objective lens, similar to the first embodiment.

Furthermore, a combination of the charged particle beam columns does not matter even in this embodiment, similar to the first embodiment.

According to the present invention, in a composite charged particle beam device having two or more charged particle beam columns, which is represented by a FIB-SEM device, a shape of the tip of the objective lens can be changed according to application. As a result, a range of sample selections which a single composite charged particle beam device can deal with is expanded. Namely, the convenience of the device is drastically improved.

#### REFERENCE SIGNS LIST

101a: Ion beam column  
101b: Ion beam  
101c: Optical axis of ion beam column

102a, 902a, 002a: Electron beam column  
102b: Electron beam  
102c: Optical axis of electron beam column  
103: Sample  
104: Sample stage  
105: Sample chamber  
106, 107: Detector  
108, 308a, 308b, 308c, 308d, 308e, 408a, 408b, 808: Detachable component  
109: X-ray detector  
130: Integrated computer  
131: Ion beam column controller  
132: Electron beam column controller  
134: Sample stage controller  
136, 137: Detector controller  
139: X-ray detector controller  
151: Controller (such as keyboard or mouse)  
152: Display  
153: GUI screen  
171: Cross point  
010: Flange

The invention claimed is:

1. A scanning electron microscope, comprising:  
an electron beam column including an objective lens;  
wherein the objective lens includes a body and a detachable component that forms a tip.
2. The scanning electron microscope according to claim 1, wherein the tip of the objective lens is formed of one of a plurality of types of the detachable component that are attachable to the body, and each of the types is made of a different material plated on the component.
3. The scanning electron microscope according to claim 1, wherein the tip of the objective lens is exchangeable depending on an analysis object.
4. The scanning electron microscope according to claim 1, further comprising an X-ray detector.
5. The scanning electron microscope according to claim 1, further comprising a display device for displaying a GUI for operating the scanning electron microscope, the display device being able to display a plurality of types of the component of the objective lens.
6. The scanning electron microscope according to claim 1, further comprising a display device for displaying a GUI for operating the scanning electron microscope, the display device being able to display a warning that a type of the component is inappropriate.
7. The scanning electron microscope according to claim 1, wherein the body of the objective lens is configured to be attachable to a plurality of types of the component, and each of the types is made of a different material.

\* \* \* \* \*